Water Column Variability in Coastal Regions

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LONG TERM GOALS

Our long term goal is to understand quantitatively the physical, chemical, and biological processes that cause variability in coastal waters. These processes include atmospheric forcing of water column properties, physical mixing and circulation, biological uptake and release of nutrients and gases, and chemical reactions at phase boundaries. This research will provide a basis to construct quantitative models for a range of properties and their variations in coastal regions.

OBJECTIVES

We are investigating the causes of temporal and spatial variability in coastal waters. Our primary focus is on oxygen, carbon dioxide, suspended particulate matter, chlorophyll, temperature, and salinity. These properties were selected because their variations reflect a wide range of processes including (I) *in situ* photosynthesis, respiration, and decomposition of organic matter, (ii) air-sea gas exchange, (iii) response to meteorological conditions (solar radiation, wind velocity, and heat fluxes), (iv) tidal mixing, stratification, water mass variations, (v) runoff from land, and (vi) anthropogenic inputs.

APPROACH

We are investigating the causes of coastal water variability by combining *in situ* sensor measurements, satellite remote sensing, and selected water column sampling and analysis. Prior to FY98 our work was conducted mainly in Rhode Island coastal waters (Kester *et al.*, 1996). We established autonomous time-series measurement systems. During FY98 we conducted joint studies with colleagues at the Hong Kong University of Science and Technology (HKUST) using these methods to examine coastal variability in southern China due to the winter/summer monsoon cycle, the annual changes in discharges from the Pearl River (the Zhujiang), and local urban, industrial, and agricultural inputs in a region of the world that has experienced very rapid economic growth over the past 15 years. Dana Kester took a sabbatical leave from the University of Rhode Island in order to devote the year to an intensive set of field measurements at HKUST. Wendy Woods also spent the past year carrying out work at HKUST that will provide much of the basis for her doctoral dissertation. In 1995 HKUST established an HRPT satellite receiving station that provides local area coverage (1 km per pixel) from NOAA AVHRR and SeaWiFS sensors. Working with Drs. Ming Fang, Gary Heinke, and Jay Chen at HKUST we formulated a project to study the processes occurring in the region of Hong Kong using satellite remote sensing, autonomous time-series instruments, and a series of cruises over the course of the year. In

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addition to this ONR project support, funding for the work in Hong Kong was provided by the Croucher Foundation and by other funds available to HKUST.

WORK COMPLETED

Andrea Magnuson and Dana Kester completed the analysis of the year-long time-series of water column properties near the entrance of Narragansett Bay. Magnuson completed her Ph.D. dissertation in December 1997; she is now doing post-doctoral research at the University of Maryland Horn Point Laboratory where she is working with SeaWiFS remote sensing and coastal data in Chesapeake Bay.

Kester and Woods conducted studies of coastal processes and chemical variability in the region of Hong Kong and the southern coast of China from September 1997 through August 1998 as visiting scientists at HKUST. We established a water column time-series measurement system in Port Shelter Bay off the HKUST campus. Endeco/YSI sondes were placed at 0.4 m depth below the surface and at 1 m off the bottom in 6 m of water to make measurements at 15-minute intervals. The sensors used included temperature, salinity, dissolved oxygen, pH, ORP, turbidity, and water level. HKUST technicians were trained in the procedures to calibrate and maintain the instruments. An automated meteorological measurement system was also established at the waterfront of the HKUST campus to measure wind speed and direction, solar radiation, air temperature, relative humidity, and barometric pressure every 15 minutes. We developed a Marine Environmental Mapping System (MEMS) for use on a small boat that consists of surface seawater being pumped onboard while underway or on station. The water passes through a flow chamber containing the same suite of sensors as are used in the time-series measurements. A flow-through fluorometer is used to detect chlorophyll variations. A differential GPS and electronic charting system was used to display and log the position of the underway measurements at 4 second intervals. We conducted a series of 18 cruises throughout the waters of Hong Kong and the lower Pearl River Estuary during the year.

We developed a version of the MEMS that can be deployed on a commercial ship of opportunity to obtain underway surface measurements autonomously. This system has been tested onboard a small container vessel that makes daily transits through Hong Kong waters.

Woods developed a semi-automated pressure filtration system to collect total suspended matter, phytoplankton chlorophyll, and particulate organic carbon during field sampling from a small boat. These data are for use with AVHRR and SeaWiFS satellite remote sensing of coastal waters.

Kester set up a four-channel fiber optic spectrometer system to provide information on the optical properties of the water column during field sampling.

We established a database of AVHRR images with 1 km per pixel resolution for several areas of the western Pacific coastal waters. The images have been processed to provide sea surface temperature (SST) and variations in SPM based on the reflectance in the visible and near infrared channels. A series of over-lapping rectangular regions were included in this database. These regions extend from the Bo Hai, East China Sea, Taiwan Strait, south coast of China, the Gulf of Tonkin, and the Luzon Strait.

During the year of work in Hong Kong we made several visits to marine laboratories in China (the First, Second, and Third Institutes of Oceanography, SOA, the South China Sea Branch of SOA, the South

China Sea Institute of Oceanology, the Marine Biological Research Station at Daya Bay, Zhongshan, Jinan, and Xiamen Universities, and the Ocean University in Qingdao.

In August 1998 Kester and Woods participated in the Sino-US Workshop on Cooperation in Marine Science and Technology which was organized by the ONRASIA Office and was held in Qingdao, China.

RESULTS

HKUST is a new university, having been established in the early 1990's to strengthen Hong Kong's capabilities in science, technology, and commerce. Its campus is located on the shore of Port Shelter Bay, a semi-enclosed bay on the east side of Hong Kong beyond the highly developed urban areas of Hong Kong Island and Kowloon. We conducted the first comprehensive investigation of processes occurring in Port Shelter Bay. The high-resolution time-series measurements of temperature, salinity, oxygen, pH, turbidity, water level have shown the effects of the seasonal monsoon, meteorological forcing, and tidal transport and mixing. The vertical structure of Port Shelter Bay was determined at approximately monthly intervals using ship-based measurements. The annual variation in vertical stratification in the Bay has a very important affect on chemical and biological processes. From March through October the waters are stratified with warmer less saline waters overlying subsurface waters that penetrate into the Bay from the South China Sea. The pycnocline occurs at 4-6 meters and the total water depth is about 20 m. The Bay is ringed by steeply sloping mountains; it has a small drainage basin. There are no significant rivers that discharge to the Bay, only a few seasonally variable streams and local runoff. We found reduced salinities in the surface waters near the more populated areas of the shoreline, and we believe this is due to the discharge of domestic waters. These waters also add nutrients (phosphorus and nitrogen) to the Bay. We found a region of the central portion of the Bay that had very high saturations of oxygen (140-150%). In this region the oxygen below the pycnocline was depleted to about 10% of saturation. During stratified periods, portions of the Bay are eutrophic and with further nutrient inputs the subsurface waters could become hypoxic or anoxic.

We examined the influence of the Asian monsoon cycle on the coastal waters of Hong Kong. From November through February there are relatively strong winds from the northeast that set up the Cold China Coastal Current from northeast to southwest. This current extends from the East China Sea through the Taiwan Strait along the south coast of China to Viet Nam. Our analysis of satellite imagery shows that the Cold China Coastal Current transports large amounts of suspended particulate matter (SPM) to the region of Hong Kong. The winter is the low flow period for the Pearl River. Its plume extends to the west of the Zhujiang Estuary during winter. From May through September the southwest summer monsoon sets up the South China Sea Warm Current which results in a 180° reversal in coastal water transport from Viet Nam to the East China Sea. Results from our field studies and satellite remote sensing show that during the summer monsoon, which is the high flow period of the Pearl River, its plume extends through the 235 islands that comprise Hong Kong. There is a substantial decrease in surface salinities, increased SPM and very high surface chlorophyll concentrations supported by high nutrient concentrations.

During the first three months of the underway ship-of-opportunity tests (Jun-Aug 98) we have been able to see the effects of changes in rainfall and river flow on the extent of the Pearl River plume as it penetrates through the region of Hong Kong. We are able to see the decrease in very high turbidity as

the waters advect into and mix with South China Sea waters. When the turbidity reaches a particular value chlorophyll fluorescence increases dramatically, which we believe is caused by the increased penetration of sunlight into the water column.

Discrete samples taken throughout the Hong Kong region provided very good calibration relationships between chlorophyll concentration and chlorophyll fluorescence and between gravimetric SPM and optical turbidity measurements. We obtained high resolution optical spectra (about 1 nm) over the wavelength range of 250-900 nm of solar irradiance, water column irradiance, water column reflectance, and spectral attenuation of solar radiation with depth. These data are providing the information needed to quantify ocean color and AVHRR VIS-NIR satellite images in the region of Hong Kong.

The analysis of AVHRR and SeaWiFS satellite images has allowed us to extend our investigations of processes occurring in the area of Hong Kong and the Pearl River Estuary to other portions of the western Pacific coastal waters. Through collaboration with Dr. Danling Tang at HKUST we have characterized the spatial and seasonal variations of surface chlorophyll in the continental shelf waters of China. We also did a comprehensive analysis of a recurring winter phytoplankton bloom phenomenon in the South China Sea southwest of the Luzon Strait; we discovered this feature in a previous investigation of CZCS imagery (Kester and Fox, 1993).

We have begun to develop several ongoing joint investigations of coastal processes along the coast of China with investigators from Hong Kong, the South China Sea Institute of Oceanology and Xiamen University. We are able to provide analyses of satellite imagery and provide information on the use of commercially available autonomous sensor measurement systems, and the investigators in China are providing us copies of their field data to assist in the remote sensing analysis. These cooperative projects build on professional exchanges with scientists in China that were begun 10-15 years ago (Hong and Kester, 1985, 1986); Wang and Kester, 1988).

IMPACT/APPLICATIONS

We are now able to see the effects of processes that cause chemical, physical, and biological variations in coastal waters of two quite different environments: Rhode Island coastal waters and Hong Kong coastal waters. There are differences between temperate and subtropical climates, between the monsoon reversal in the South China Sea and the prevalent westerly storm patterns of the northeastern US, and phase reversal between winter/summer and wet/dry seasons (in RI the wet season is typically the winter months whereas in Hong Kong the wet season is during summer). In spite of these differences we are seeing some very consistent processes that affect coastal variability in both places. Photosynthetic oxygen production and phytoplankton blooms vary with the amount of sunshine and cloudiness. Stratification, that allows increases in vertical chemical gradients, varies with the phase of the moon due to differences in spring/neap tidal amplitudes. Bloom events are of relatively short duration, typically 3-5 days. We also see significant differences between these two areas with the region of Hong Kong greatly affected by the discharge of a major river system that reduces salinity, increases turbidity, and brings nutrients into the coastal waters. We also see larger effects of anthropogenic inputs in the Hong Kong/Pearl River Estuary than in most portions of RI coastal waters. The similarities and differences between these two regions gives us a more complete picture of the major processes and of the response of coastal systems to different forcing functions.

TRANSITIONS

The results we have obtained in RI are being used by investigators at the National Marine Fisheries Service Narragansett Marine Laboratory (NMFS-NML) in their evaluations of trends and variations in coastal ecosystems. The RI Department of Environmental Management (RI-DEM) has become very interested in the high-resolution time series measurements in the Bay and its use to detect water quality problems before they become critical. The methods developed in this work are being used by investigators at HKUST to continue the study of coastal processes in Hong Kong. Prof. Huasheng Hong, at Xiamen University, is beginning to use continuous underway surface measurements and satellite remote sensing in their studies of the Taiwan Strait. They have expressed interest in continuing our joint work with them in these studies. They have agreed to work with us in establishing a ship-of-opportunity measurement program across the Taiwan Strait between Xiamen and Kaoshing, when funding can be obtained.

RELATED PROJECTS

By using funds provided by NOAA, which are mainly for the purchase and upgrade of additional buoy and sensor systems, we are extending the RI coastal measurement system to examine the exchanges of waters between the continental shelf and Narragansett Bay. NOAA-NMFS and RI-DEM need a measurement system in the upper part of the Bay. Along with our mid-Bay system and similar measurements near the entrance of the Bay we will be able to track changes in lateral gradients and exchange with offshore waters.

At the ONR-sponsored Sino-US Workshop on Cooperation in Marine Science and Technology we formulated a joint project with colleagues at Xiamen University to investigate the fluxes of waters, dissolved, and particulate substances in the Taiwan Strait that links the South China Sea and the East China Sea. Some initial work on this topic has begun, and we will seek additional support for it in FY-99.

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